Guided Wave Micro-Opto-Electro-Mechanical Sensors

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ABSTRACT

In this paper Micro Opto Electro Mechanical (MOEM) sensors involving the influence of bulk micro machined silicon structures on light propagation in integrated optical devices formed above these are reviewed. It is observed that these sensors have superior characteristics compared to conventional sensors as well as the emerging MEMS based sensros for application to automobile and aerospace applications. The coverage includes mechanical design issues, optical device features and limitations due to various types of noise. Recent work undertaken in the authors laboratory on pressure, vibration and acceleration sensors will be included in the presentation.

Keywords: MOEMS, integrated optics, bulk micro-machining

1. REVIEW

In this section a brief review of some MOEM sensors is presented.

Micromachining technology opens up many new opportunities for optical and optoelectronic systems,,[1].[2] It offers unprecedented capabilities in extending the functionality of optical devices and the minituarisation of optical system. Movable structures, microactuators and microoptical elements can be monolithicallyy integrated onto the same substrate using batch processing technologies. MEMS technology combines mechanical structures with electronics to perform mechanical motions, offering a host of actuators and wide application in optical systems. Merging micro-optics, microelectronics and micro-mechanics creates a new and broader class of micro-opto-electro-mechanical (MOEM) devices that are more efficient than the marco scale devices and are attracting many commercial applications. Torsional micromirrors, digital mirror device (DMD), laser scanners, FFDI bypass switches, tunable Fabry-Perot etalons, optical interconnects, optical data storage devices are some examples.

Many applications of guided wave MOEMS reported so far are about the sensing applications. The sensors can be classified according to the application domain such as mechanical, thermal, optical, fluidic, chemical, biological etc. Micromachined optical sensors can be used for all the above categories. They rely on the principle of change in amplitude, path direction, phase or polarisation of the guided wave light by the external perturbation on the micromechanical structure.

Guidedwave optics in combination with microstructure offer an attractive potential for chemical abd biological sensing. For these types of sensors, substrate silicon just plays a passive role and focus is mainly towards new chemistries and optical methods for sensing. Most of the integrated optical micromachined chemical or biological sensors utilise a Mach Zhender Interferometer (MZI) or surface plasmon resonance (SPR). In the MZI category **??**, the sensing arm is coated with a chemically or biologically sensitive layer that modifies the refractive index of waveguide due to abosrption. This index change is readout as intensity change in MZI.

Fabricious et. al. [?] have demonstrated a gas sensor and Boairski et. al. [?] have developed an immunogloblin-G and staph entrerotoxin-B sensor using this method. The surface plasmon excited in metal surface deposited over a waveguide surface is strongly attenuated by absorption by a species such as gases or molecules bound to the metal surface producing a change in the propagation constant, and is read out opticaly as intensity change. This principle was used by Lambeck et. al [?] to detect gases.

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2. SPECIFIC SENSORS

In this section research work on guided wave MOEM sensors being undertaken in our lab is presented.

A typical MOEM sensor consists of a mechanical structure such as a cantilever beam or a diaphragm formed by anisotropic bulk etching of silicon substrate. Over and above this, layers of silicon dioxide and/or silicon nitride are formed resulting in an optical layer. Guided wave optical devices like a Mach Zhender Interferometer or a directional coupler are etched out in this layer. Additional layers of polymers or bilogically active materials can provide addtional layers and functionality.

Fig.1-4 show several examples of guided wave MOEM sensors. A typical pressure sensor consists of a MZI on a rectangular diaphragm. The sensing arm of the MZI is positioned at the edge of the diaphragm to take advantage of the maximum opto-mechanical effect due to the stress induced change in the refractive index of the waveguide. The design of such a device calls for the mechanical analysis and the optical analysis. Also the infulence of various types of noise such as mechanical noise, electronic noise of the detector and the photon quantum noise on the performance is important.[11]

Table 1-3 show a comparison of performance of various types of MOEM sensors. Devices based on changes in wavelength resonances in optical waveguides have attractred attention in recent times due to the advances in Dense Wavelength Division MUltiplexing (DWDM) based optical communication systems. It should be noted however the wavelength shifts of much smaller magnitude than in optical communications need to be detected in sensor applications.[10]

Integrated optic finds applications in optical signal processing of sensor data.[9] Optical signal processing of optical sensor data is an attactive option compared to electronic signal processing. Recenlty theres is much interest in structural health monitoring (SHM) of aerospace, civil and other structures using optical sensors such as fiber Bragg grating arrays. Integrated optics will find application here in terms of interrogating and interpreting the data received from these sensor arrays. As a example a typical fiber optic sensor making use of a fiber sensor coil requires in addtion a polariser, an isolator, a branching element, and an electro-optic phase modulator. Integration of all these on a same crystal is advantageous in terms of perfromance as well as size/weight/cost considerations. Ultimately replacing the fiber coil itself by a MOEM device could result in an optical gyroscope on a chip.

3. CONCLUSION

To sum up, the incorporation of microstructures with integrated optics offer many advantages and possibilities that otherwise are difficult to obtain. It provides optically active properties to otherwise opticaly inactive silicon based IO circuits. The planar technology allows the integration of IO with microstructures and microelectronics. The III-V semiconductors will provide better integration as the sources and detectors too can be integrated on the same substrate along with the optics and mechanics. The development of III-V based guided wave optical MEMS devices are still in infancy and the process costs are much higher. But in the future, as technology matures, it will be more prefered.

4. ACKNOWLEDGEMENT

The author would like to acknowledge his research students Dr. J Nayak, Dr. P.K Pattnaik Mr. Bh V Aditya and Ms. S. Malathi for their research work presented in this paper

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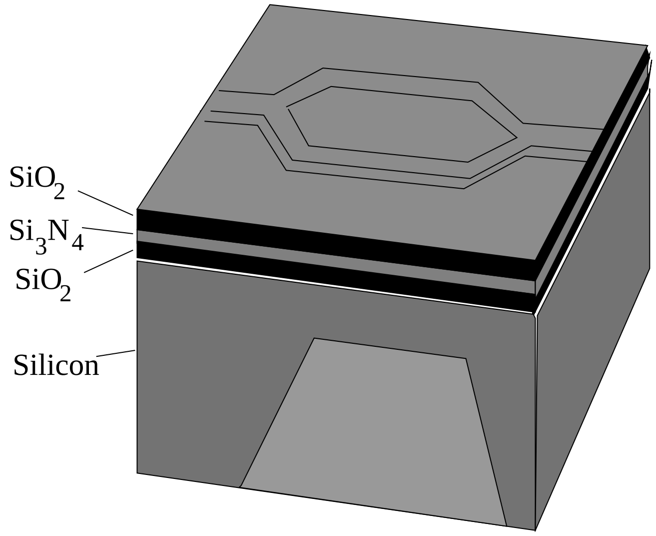

Figure 1. MOEM MZI-Diaphragm based Pressure Sensor

Table 1. MEMS and MOEM Pressure Sensor Comparison

Sensor Type	Sensitivity Defination	Sensitivity Expression	Value $(10^{-4}/kPa)$
Piezo-resistive	$\frac{\Delta R}{PR}$	$(\pi_l + \nu\pi_t)\, S_{max} \left(\frac{b}{h}\right)^2$	8.45
Capacitive	$\frac{\Delta C}{PC}$	$\frac{12\left(1-\nu^2\right)}{E} \left(\frac{b}{h}\right)^4 \left(\frac{h}{d}\right)$	132.92
IO MEMS	$\frac{\Delta I}{PI}$	$4\pi \frac{n}{n_{eff}} \frac{a}{\lambda} \left(\frac{b}{h}\right)^2 C_2 S_{const}$	454.8

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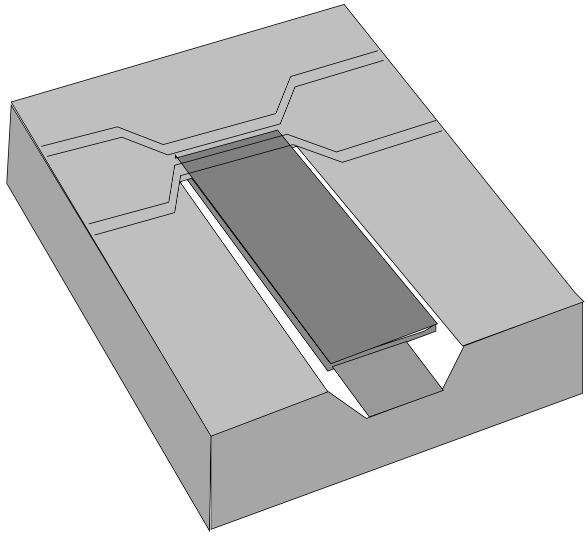

Figure 2. MOEM DC-Cantilever based Vibration Sensor

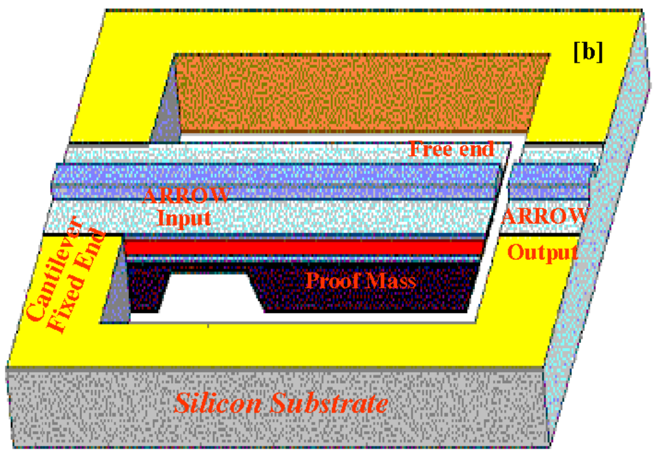

Figure 3. MOEM Waveguide gap Acclerometer

Table 2. MEMS and MOEM Vibration Sensor Comparison

Sensor Type	Sensitivity Defination	Sensitivity Expression	Value $(/mg)$
Piezo-resistive	$\frac{\Delta R}{aR}$	$(\pi_l + \nu\pi_t)\frac{6mg(l_1+l_2/2)}{bh_1^2}$	1.66
Capacitive	$\frac{\Delta C}{aC}$	$\frac{4mg}{dEb}\left(\frac{l_1+l_2/2}{h_1}\right)^3$	15.02
IO MEMS	$\frac{\Delta I}{aI}$	$\frac{4\pi}{\lambda}\frac{n}{n_{eff}}\frac{6mg(l_1+l_2/2)}{h_1^2}C_2$	99.8

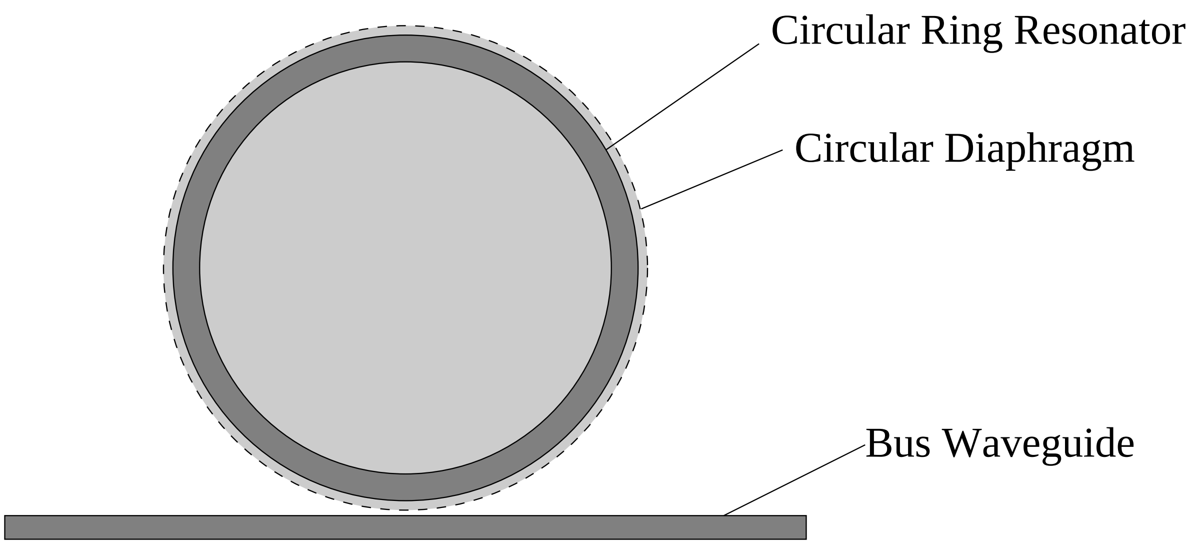

Figure 4. MOEM Ring Resonator Pressure sensor

Table 3. MEMS and MOEMS Acclerometer comparison

Parameters	Force balance	Vibrating beam	Fiber optic	SAW	MEMS (bulk micro-machined)	MOEM* 1 (open loop)	MOEM * 2 (closed loop)
Input range (g)	±100	±200	±20	±100	±100	1-25	25-160
Threshold (μg)	10	<10	1	1-10	1-10	5-0.25	0.25
Scale factor stability (ppm)	1000	100	1	1000-5000	5000-20000	<1 ppm	1 ppm
Bandwidth (KHz)	0.4	0.4	0.1	0.4	0.4	0.4-1.5	25